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EXPLOITATION OF WIND ENERGY

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EXPLOITATION OF WIND ENERGY

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DEVELOPMENT AND PROSPECTS

The development from the slowly turning windmills to the fast-turning wind wheels of small modern wind power plants may be compared to the transition from overshot and undershot waterwheels to the modern Kaplan turbines. Only over the last thirty years has power generation using wind energy been investigated from the economic standpoint. While most European countries confined themselves in this period to small research plants, many small wind power plants were placed in operation to supply remote farms in Denmark [1] and the Soviet Union, in the thirties and forties. The Reich Wind Energy Research Association, Berlin, since its inception in 1944, has chiefly been collecting test reports on existing installations, but has also performed theoretical research. /320*

After the second world war, the Energy Committee of the German Federal Council was for a time occupied with wind energy problems. More recently, the Federal Ministry of Economic Affairs, with a view to furthering development, asked the Association of German Electric Power Plants in Frankfurt to act as an information clearing office and to pursue development in the sphere of wind energy. Shortly before this the Wind Energy Research Association, Inc., Stuttgart, was founded with the cooperation of the Wurttemberg government and of various industrial and electricity concerns. This Association is presently extending its activities, over which the Association of German Electric Power Plants is to have a controlling influence.

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*Numbers in the margin indicate pagination in the foreign text.

In the spring of 1950 a working group on wind energy was set up within the Organization for European Economic Cooperation (OEEC) in Paris, in which the German Federal Republic is represented.

For a time, designs from a number of ingenious inventors (among whom was Honnef) aroused considerable interest in Germany and abroad. These would permit the construction of wind energy plants generating 20,000 kW on 250-meter towers with wind wheels 180 meters in diameter, although present-day technology is not able to bring these plans to reality. The prevailing expert opinion is that small research plants with a 100 kW output will be extended into larger installations. Two to three thousand kW is now being talked about as the ceiling with existing technology. Before these are built, however, a number of problems still have to be cleared up: we are still very much in the early stages. Problems arising from parallel operation feeding into a public network have been studied in theory, but not resolved in practice. Large-scale exploitation of wind energy still lies far in the future.

THE PROPERTIES OF WIND

One of the prime conditions for utilizing wind energy is knowledge of the properties of the wind. Thus far, usable data has been available only from a very few countries. Despite the extended network of weather bureaus in all developed countries and despite the comprehensive data collected for decades in these bureaus and in airports, it must be said that available observational data has large lacunae and suitable instruments must be built and tested for measuring and recording wind velocity and power. Information exchange in this area is one of the most important tasks of the OEEC working group on wind energy.

WIND VELOCITY AND DETERMINATION OF WIND POWER

Wind power increases according to approximately the cube of wind velocity[1]. If we look at the chart of a recording anemometer we see that even with moderate wind forces the velocity often fluctuates within seconds by a factor of two or more. Thus, the power fluctuates by the cube of this factor, i.e. eight or more. Calculation of wind power at a specific point, when weather bureau wind statistics usually represent three daily wind velocity readings, is therefore rather imprecise. Moreover, very few weather bureaus are in locations exposed to the wind. Accordingly, a start was made in France about three years ago to set up a network of 100 bureaus for continuous recording of wind power. These bureaus are at exposed points (on lighthouses, electric pylons, etc.) which are affected as little as possible by ground eddy zones. In England a similar observation network has been set up in the last few years, chiefly on the west coasts of the British Isles. In Germany the Wind Energy Research Association, in coordination with the main meteorological offices, sought out in the first instance about ten points favorable for recording wind velocities.

This study of wind behavior has shown that within the ground eddy zone, even in flat areas, there are striking differences in wind velocity. According to the structure of the terrain, isolated hills or points lying in the prevailing wind direction can show 20 to 50 percent higher average velocities, and therefore twice or four times the wind power, of the average taken from surrounding and further-lying areas.

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[1]The maximum value for the theoretical power of a wind wheel occurs when the downwash speed behind the wheel amounts to 1/8 of the incident wind speed: $N_{max} = 16/27 \cdot F \cdot v^3 \cdot RHO/2$ (mkg/s) in which RHO is the air density (kg sec^2 m^{-4}) and F is the area swept by the wind wheel (m^2). The actual power is only 0.4 to 0.8 of the theoretical power.

WIND MEASURING INSTRUMENTS

Only reliable, sturdy, and relatively maintenance-free recording instruments are suitable for measuring wind power. There are basically two different ways of determining the usable wind energy at a given point. In one case the distance traveled by the wind is plotted continuously as a function of time for the observation point. From the average slope of this path-time curve against the abcissa, the mean wind velocity v_m and the energy E for a given time T can be determined:

$$E = k \int_0^T v_m^3 \, dt \text{ (mkg)},$$

wherein the factor k accounts for the air density, the area of the wind wheel, and the power factor.

Evaluation of such wind-path diagrams is extraordinarily time-consuming. To determine the usable wind energy, we must allow for the fact that wind velocities less than 5 m/s and over about 12 m/s are generally unusable in practice for technical reasons. The other method uses a small wind wheel directly driving a small generator whose output is recorded continuously /321
so that the usable wind energy may be read off directly. While with one method, with almost inertia-free contact anemometers, the wind velocity or wind path can in theory be found with almost 100% precision, with the second method the inertia of the wind generator and its efficiency varying widely with rpm fluctuations must be reckoned with. One fact is in our favor: the measuring generator runs with almost uniform efficiency within the wind velocities of 5 to 15 m/s which concern us in practice.

WIND GUSTING

The effect of gusting on performance of a wind wheel working in parallel with a network which must turn with a constant rpm due to the line frequency, even if the wind velocity varies within wide limits in a short time, still has to be studied thoroughly. In a wind measuring station in the Orkney Islands a 40-meter mast rotatable about its axis was erected for this purpose, with four anemometers in a cruciform pattern which record the wind velocity synchronously. With this system, conclusions can be made as to the gusting distribution over the entire area swept by a wind wheel.

INFLUENCE OF HEIGHT ABOVE GROUND

The wind velocity increases regularly as a function of height above ground, except for frequent irregularities in the ground eddy zone. For this reason results obtained in one location cannot be transferred directly to another. This regularity can also change with wind direction in any given location. Since it is impractical to make continuous recordings at great heights (100 to 300 meters), the working group on wind energy of the OEEC has agreed that measurements should normally be taken 10 meters above ground, or measurements made at greater heights should be converted to 10 meters. To determine the curve of the increase in velocity with height, pibals or smoke rockets fired vertically upwards can be used. The smoke threads blown by the wind can be recorded on film and a comparison between photographs shows simultaneous velocities at various altitudes.

ISOVENT CARDS

In some countries use is being made of "isovent cards", as they are called, on which points of identical mean wind velocity are joined by curves. This gives a synoptic view of exposed points in Europe, mainly along its western coasts. In this way, a mean wind velocity of about 7 m/s has been found for the Brittany coasts, 6 m/s for Normandy, and about 8 m/s for Ireland. Favorable values are also found for the German North Sea coast, the west coast of Jutland, and part of the Mediterranean coast. However, there is a relatively small number of points truly favorable for wind. In the interior of the continent and of islands and peninsulas the mean wind velocity sinks to half this value or less; accordingly the usable wind energy is 1/8 or less. Exceptions are some peaks in the German central mountains, e.g. the Feldberg in the Black Forest, the Brocken in Harz, and the highest peak of the Rhone.

WIND WHEEL DESIGNS

SMALL PLANTS

Wind power plants on a public network are as good as non-existent. Up to the present, small plants with outputs of 2 to 15 kW according to wheel size and wind velocity supplying remote farms have been built, mainly for export.

In West Germany, the series of 8 kW plants built by the Allgaier Company in Uhingen, Wurttemberg, is familiar. The wheel with 10 meter blade diameter and three adjustable blades is located behind the tower. The blades are started up manually and they shift automatically if overloaded. They normally rotate at 86 rpm. A small lateral wind wheel points the main wheel into the wind. The three-phase generator, 1500 rpm, 220/380 V, with gears interposed, is mounted on the rotating cap of the tower. The generator is connected to a storage battery. The 15/25 HP Nordwind GmbH plant in Porta Westfalica should also be mentioned. A three-blade wind wheel rotates in front of the 20-meter tower. The 18 kW 100/160 V DC generator is designed to rotate at 1000/1620 rpm. A small control wind wheel is mounted behind the tower[2].

The Andreau company in France has recently brought out a mass-produced plant in which the air is impelled outwardly by centrifugal force through the hollow blades of the wind wheel mounted atop the tower, and is sucked back through a vertical pipe in the tower. A second wind wheel on the ground is driven by this air current, and in turn drives the generator. Evidently,

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[2] For a detailed description of the plant, see Mackenthun [2].

the efficiency is lower here than with a wheel coupled directly to a generator, but this disadvantage is offset by the advantageous location of the generator on solid ground. Large numbers of similar small plants have been built and assembled in Denmark, for instance (wheel diameter 8 m, two fixed blades with movable tips for shutdown, u/v = 5.4 and N_{max} = 13 kW).

MEDIUM-SIZED PLANTS

Both the Wind Energy Research Association in Stuttgart and the wind energy working group of the OEEC, Paris, agree that plants on which parallel operation with large three-phase networks are to be studied must always have an output on the order of 100 kW. A plant of this size is to be built in Wurttemberg with the support of the Wind Energy Research Association. England has a plant with the same output under construction in the Orkney Islands - a windy area. In addition, a 100 kW plant in Wales and an 80 kW plant in Denmark are to be built.

FEEDING INTO THE PUBLIC NETWORK

The irregularity of the wind entails many still unresolved building problems in the areas of sturdiness, fluctuation, and, last but not least, adjustment to match rapidly-fluctuating wind velocities. More problems arise with feeding into the network. One idea has been to connect wind power plants with pumped storage plants; but these must be built as well since there is no correspondence with the pump and turbine operating times governed by normal network loads. One would use the pumps at times of high wind, then have to switch over the turbines at times of mild winds. However, these periods alternate unpredictably, often quite rapidly, and the periodicity cannot be calculated in advance.

The most important point is that the wind energy can only be /322
used in the public network as three-phase current. The attempts

to make wind wheels operate on variable-frequency alternating current, or to change direct current to constant-frequency three-phase current, require complex converters, with associated efficiency losses, and are moreover expensive. Papers by Professor M. Kloss, Berlin [3] and Dr. Hutter, Uhingen, Wurttemberg [4], have shown that it is unnecessary either to maintain constant rapid running or to adjust the blades during operation with varying wind velocities. However, it is extremely useful for the blades to be adjustable when starting up and to avoid overloads with increasing wind velocities. Development and construction of pilot plants in which experience with parallel operation on extensive networks is to be collected will therefore proceed in this direction. Plants will be kept to a size that makes possible valuable investigations into the adjustability, effects of vibrations in the tower and blades, and suitable design of gears and generators.

ECONOMICS OF WIND POWER PLANTS

Mass-produced small plants for supplying individual farms cost between 700 and 1200 DM per kW and are therefore extremely economical, generally speaking, in comparison with other types of energy when wind conditions are moderately favorable and uniform. As yet, nothing can be said about the economics of medium and large plants. The figures in the literature are mostly based on estimates. The construction costs of prototypes cannot be used to estimate the economics, as mass production after development costs have been amortized will bring about sharp price reductions.

When comparing the costs of wind energy with traditional energy sources such as coal, oil, and water, the value of the wind generated current is the prime consideration. Due to the inconstancy of the wind its value is slight: it cannot be evaluated correctly until practical tests have been made with medium-sized plants operating in parallel with the public network, and until further searching studies have been made of the properties of wind.

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